SUSTAINABLE DEVELOPMENT OF RURAL AREAS IN SIBERIA IN THE CONTEXT OF GLOBAL CLIMATE CHANGE

Marina Petukhova
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Novosibirsk State Agricultural University, RUSSIA
petuhova_ms@nsau.edu.ru

Abstract

The article is devoted to determining the prospects for long-term development of rural areas of the Siberian Federal District in the context of global climate change. The study is based on the predicted calculation of changes in hydrothermal conditions within the boundaries of natural and climatic zones of Siberia. It was revealed that by 2050 the predicted shift of natural and climatic zones will be on average 50-100 km depending on the region in the direction from south to north. In some regions (Krasnoyarsk Krai, Novosibirsk, Tomsk and Kemerovo Oblasts) by 2050 there will be a significant improvement in natural and climatic conditions that have a favorable effect on agriculture. Scenarios for the long-term development of rural areas of the Siberian Federal District in the context of global climate change have been developed: "Climate Adaptation", "Climate Mitigation" and "Climate Crisis". Sustainable development of rural areas in Siberia is possible within the framework of the "Climate Mitigation" scenario, which implies mitigating the risks of global climate change through the development of fallow lands, agroforestry, crop rotation, organic farming, etc.

Keywords: rural areas, global climate change, scenarios, climate adaptation, climate mitigation, climate crisis

I. Introduction

Modern challenges affecting the issues of global climate change and its predicted impact both on the agro-industrial complex (hereinafter referred to as the AIC) and on the rural areas that provide it, require the formation of an adequate technological, social and economic response now. That is, this problem can be considered exclusively in the context of the paradigm of sustainable development, which combines these three areas. It is a comprehensive response, implying the development and implementation of innovative AIC technologies adapted to climate change, the creation of new types of organizational forms of rural settlements, the emergence of new types of rural employment, and ultimately the likely expansion of the geography of settlement of the rural population to the north of Russia, that will reduce the risks of global climate change for the AIC and rural areas. This issue is especially relevant for the rural areas of the Siberian Federal District, which are located above the 55th parallel, where, according to climatologists, the greatest consequences of climate change will be observed.

The purpose of this study is to identify promising areas for the sustainable development of rural areas of the Siberian Federal District in the context of global climate change.

II. Methods

The following methods were used as the methodological basis for the study: methods of analysis and synthesis, scenario forecasting, calculation and design and cartographic methods.

The territory of the study is the Siberian Federal District (SFD), which includes 10 subjects

(the Altai Republic, the Republic of Tyva, the Republic of Khakassia, Altai Krai, Krasnoyarsk Krai, Irkutsk, Kemerovo, Novosibirsk, Omsk and Tomsk regions). As part of the study, a predicted change in the boundaries of natural and climatic zones in the SFD by 2050 was constructed based on the calculation of hydrothermal conditions. To assess the change in hydrothermal conditions in the SFD, the Selyaninov hydrothermal coefficient, HTC [1], was used, which is currently widely used in the practice of Roshydromet as the main quantitative indicator of the ratio of heat and moisture. The distribution of HTC is in good agreement with geobotanical zones and, in fact, reflects the differentiation of landscapes. To construct the climate projections of the Selyaninov GTC up to 2050, climate projections of air temperature and precipitation amounts obtained from CMIP6 data (scenarios SSP1-2.6 and SSP5-8.5) and adjusted similarly to [2] were used. Previously developed software modules [3] were used to calculate values for individual years and average long-term values in the reanalysis grid nodes and CMIP6. The result of the modules' work is files in the netCDF format.

III. Results

Previous studies [2,4,5] have shown that there is already a shift in the boundaries of natural and climatic zones in the Siberian Federal District, mainly from south to north. It is less noticeable in the steppe zone of the district and quite obvious in other natural and climatic zones. Depending on the generally accepted socio-economic scenarios of the Intergovernmental Panel on Climate Change (IPCC) - SSP1-2.6 and SSP5-8.5, the shift in boundaries can be from 50 to 150 km by 2050 [6]. It should be taken into account that in this study, the shift in zones is understood as a change in the boundaries of zones with a certain heat and moisture supply (certain values of the HTC). That is, in the next 30 years, favorable climatic conditions will be created for changing the areas of vegetation corresponding to certain natural zones. It is also worth noting that the SSP1-2.6 scenario is a sustainable development scenario, i.e. the most optimistic option (shift by 50-70 km), and the SSP5-8.5 scenario is an unfavorable option, assuming further development of the country's economy on fossil fuels (shift by 100-150 km). Within the framework of the second scenario, according to the Sixth Assessment Report, very high greenhouse gas emissions are predicted: by 2075, CO2 emissions will triple threefold. Each of the listed SSPs provides a future forecast of greenhouse gas emissions and land use changes in accordance with its baseline. In most cases, development according to the SSP5-8.5 scenario will lead to more rapid changes and the advancement of zone boundaries will occur at a distance twice as large as in the SSP1-2.6 scenario [7, 8].

Figure 1 shows a cartographic representation of the predicted change in the boundaries of natural and climatic zones in the territory of the Siberian Federal District subjects. By 2050, the predicted shift of natural and climatic zones will average 50-100 km, depending on the region. During this period, a statistically significant increase in the duration of periods with average air temperatures above 0, +5, +10 °C is predicted, which will have a positive effect on extending the growing season in most of the district.

In addition, there will be an increase in areas with hydrothermal conditions that characterize steppe and forest-steppe landscapes suitable for agricultural production.

Thus, the shift in natural and climatic zones in the Siberian Federal District will become a key factor in the possible change in the structure and directions of economic activity in rural areas. In some regions (Krasnoyarsk Region, Novosibirsk, Tomsk and Kemerovo Region), by 2050 there will be a significant improvement in natural and climatic conditions that have a favorable effect on agriculture. Here it will be possible to expand the area of crops, including by introducing fallow lands into agricultural circulation and growing new types of crops. At the same time, in the republics of Altai, Khakassia and Tyva, in the Irkutsk Region, an increase in aridity of the territory

is predicted, which will lead to a decrease in the share of agriculture in the gross municipal product.

Novosibirsk Region (expansion of the northern boundaries of the zones of provided and excessive moisture up to 100 km, the arid zone in the south of the region - up to 75 km) - expansion of the area under grain and leguminous crops, oilseeds by reducing the area of swamps. Involvement of fallow lands in agricultural circulation, development of organic agriculture. Creation of new eco-settlements.

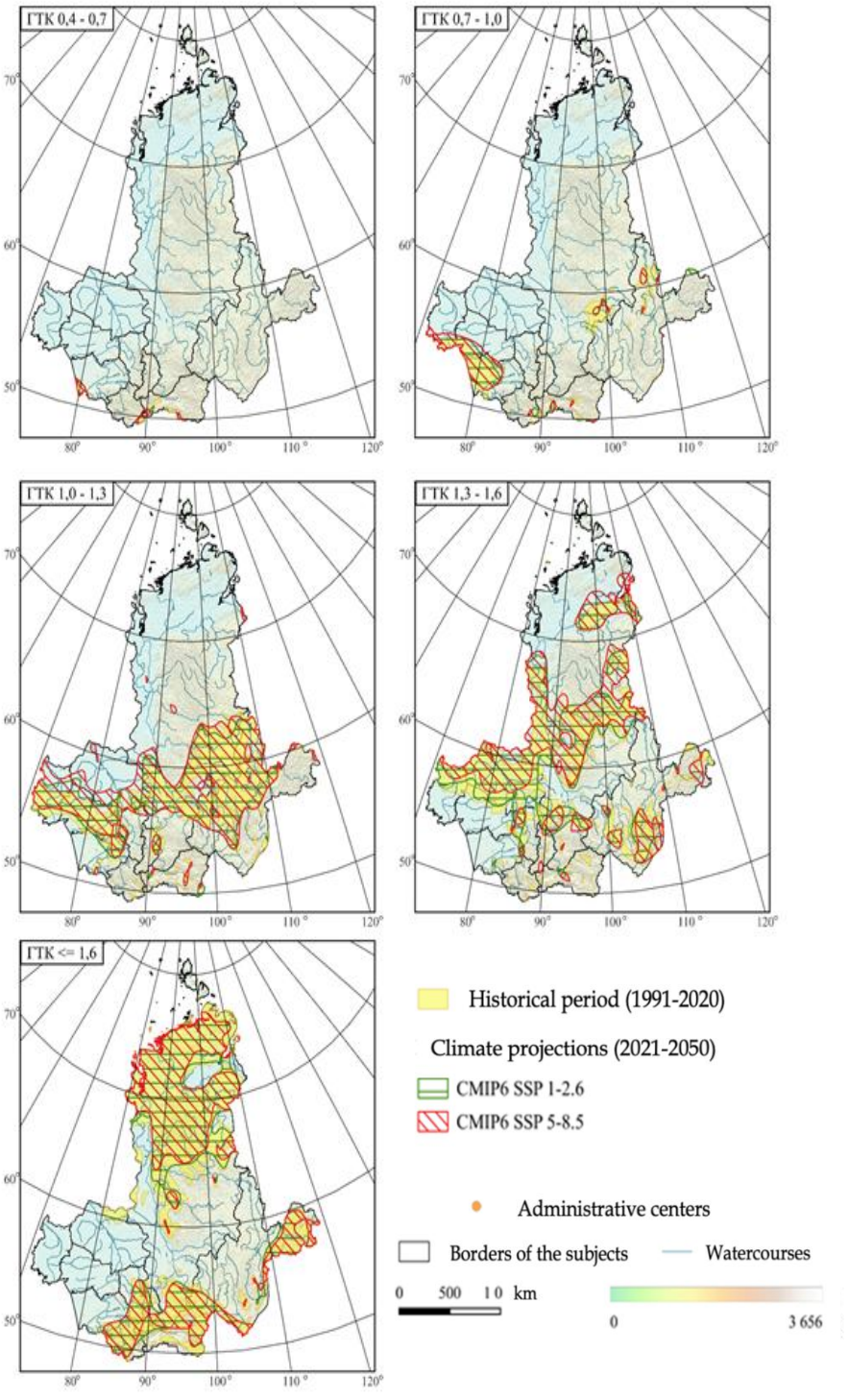

Figure 1: *Forecast zones of humidification by the values of hydrothermal coefficient. Siberian Federal District*

Altai Republic (southeast - semi-desert, shift of the moisture zone to the north) - reduction of sown areas and pastures. Diversification of the rural economy, moving away from agriculture. Development of rural tourism, cultivation of medicinal plants. Development of organic livestock farming. Creation of new eco-settlements.

Krasnoyarsk Region (reduction of the area of excess moisture zones, expansion of the zone of provided moisture. In the east - the appearance of forest-steppe landscapes) - expansion of spring wheat, oilseeds and legumes. Growing winter crops. Possibility of using late-ripening varieties in the south of the region. Creation of new rural settlements and shift camps to provide food for oil production facilities.

Republic of Tyva (predominant zone of excessive waterlogging. Southwest – semi-desert. In the central regions, the zones shift up to 200 km) – strong negative impact of climate change on the rural economy will lead to a reduction in agricultural production.

Republic of Khakassia (no significant natural and climatic changes are observed) – introduction of new areas into agricultural circulation, including fallow lands for organic farming. However, the use of drought-resistant varieties is required due to the increasing aridity of the climate.

Altai Region (expansion of the steppe zone, reduction of the forest-steppe. Shift of zones up to 150 km to the northeast) – cultivation of drought-resistant crops, reduction in grain production. Development of rural tourism.

Omsk Region (decrease in humidity of the territory, with the advancement of zone boundaries to the north) – adverse impact of global warming on the rural economy, reduction in agricultural production. Tomsk Region (shift of excess moisture zone to the north – up to 150 km. The entire territory of the region is an excess moisture zone) – possible increase in crop production due to reduction of swamp areas. Creation of shift camps to provide food for oil production facilities.

Irkutsk Region (increase in the area of arid zones by 40-60 km to the south. In the central regions – over-moistening) – adverse impact of global climate change on crop production. Development of rural tourism.

Kemerovo Region (predominant zones of provided and excess moisture) – diversification of crop production, cultivation of oil crops, development of organic agriculture.

It has been revealed that the natural and climatic zones of Eastern Siberia are "moving north" faster than those of Western Siberia. This is especially true for Krasnoyarsk Region, where as a result of such changes, more and more zones are emerging that are favorable for agricultural production. In this region, the zone of provided moisture is expanding, and new forest-steppe landscapes are appearing. In the Irkutsk Region, opposite trends will be observed: an increase in the area of arid zones in the south and over-moistening in the central part of the region.

IV. Discussion

The study revealed that in the southern regions of the Siberian Federal District (the Republics of Tyva, Khakassia and Altai, Altai Krai), an increase in the average annual temperature leads to a decrease in the yield of grain and leguminous crops, while in more northern regions (Krasnoyarsk Krai, Tomsk and Novosibirsk Oblasts) - on the contrary, to an increase, which is confirmed by the correlation coefficients. The contribution of temperature growth to the change in yield is on average 10-20% [2]. That is, it can be concluded that global warming will have the most favorable effect on the subjects of the Siberian Federal District located in the north of the macroregion. Global warming here will be accompanied by an increase in the growing season, a longer frost-free period, etc. It will be possible to grow new varieties of crops, including late-ripening ones. Improved natural and climatic conditions will allow the introduction of fallow lands into agricultural circulation, which can be used, among other things, for growing organic agricultural

products. In the southern regions, the increase in climate aridity will lead to an increase in the number of droughts and, accordingly, a reduction in crop yields. In these regions, it is necessary to use drought-resistant varieties of agricultural crops, introduce pre-sowing seed treatment technologies and apply mineral fertilizers.

The author proposes three scenarios for the long-term development of rural areas in the Siberian Federal District in the context of global climate change: "Climate Adaptation", "Climate Mitigation" and "Climate Crisis". The basic scenario condition for all three scenarios is the shift of natural and climatic zones from the south to the north of the macroregion.

Within the framework of the "Climate Adaptation" scenario, the rural economy will adapt to the predicted natural and climatic changes. It is necessary to use drought-resistant plant varieties, change the timing of agro-technological work, increase the use of mineral fertilizers and chemical plant protection products, and irrigation systems to preserve crops. The main measures to adapt to climate change will be the implementation of hydromelioration and other reclamation measures, coastal protection and clearing of river beds, and the restoration of degraded lands [9].

As a result of the implementation of these measures, the impact of climate change on agricultural production will be minimized (reduction of losses from natural disasters - droughts and floods) [10]. An example of adaptation measures in Russia is the restoration of 7 km of the historical Ural River bed in the Orenburg Region as part of the national project "Ecology".

In regions where the efficiency of agricultural production continues to decline, the rural economy will be reoriented to new sources of growth, as mentioned above. "Climate adaptation" is a basic scenario for the long-term development of rural areas in Siberia, which assumes the extrapolation of existing trends.

The "Climate mitigation" scenario involves the development of measures aimed at eliminating or reducing the long-term risks of climate change. This scenario should be based on sustainable development of agriculture and rural areas, integrating economic growth, social well-being and ecological balance. This is an optimistic option for long-term rural development, implying a reduction in greenhouse gas emissions from agricultural production.

The following natural climate solutions should be implemented within the framework of the "Climate Mitigation" scenario:

1) agroforestry, sanitary felling, optimization of logging operations;

2) accumulation of organic matter in the soil and reduction of soil carbon losses in arable land and meadows;

3) crop rotations;

4) reclamation of degraded lands and reduction of nitrogen losses when applying mineral and organic fertilizers;

5) agrotechnical measures to prevent salinization and soil degradation;

6) cultivation of perennial plants;

7) pasture management.

In addition, "Climate Mitigation" requires the development of measures to significantly reduce forest fires, which is extremely important for the territory of Siberia.

Thus, the condition of this scenario should be the introduction of resource-saving technologies both in agriculture and in land use.

The result of this scenario will be the introduction of new areas of agricultural land into circulation, diversification of agricultural crops, growth in crop yields and animal productivity, and the creation of new rural settlements. For example, in the Altai Territory, the ANO "Center for Environmental Innovations" leased agricultural land in the Zalesovsky District with an area of 10 thousand hectares for 49 years. Where forests were planted to absorb greenhouse gases.

The "Climate Crisis" scenario assumes the absence of any measures on the part of local, regional and federal authorities and the population to adapt and/or mitigate economic activity to natural and climatic changes. This will lead to the extinction of villages and an increased outflow

of the rural population to the city. Agriculture, as one of the main sources of income for the rural population, will be exposed to increasingly frequent extreme natural and climatic conditions, which will lead to the loss of sustainability of rural households. The absence of measures to prevent the consequences of global climate change will further accelerate the warming process due to increasing greenhouse gas emissions. "Climate Crisis" is a negative scenario for the long-term future of rural areas of Siberia, threatening Russia's food security. According to the authors, the most optimal direction for long-term development of rural areas of the Siberian Federal District in the context of climate change will be the integration of two scenarios: "Climate Adaptation" and "Climate Mitigation", within the framework of which adaptation measures will be jointly implemented, as well as the prevention and mitigation of the risks of global climate change.

The authors identified the following as key technologies for mitigating rural development to climate change:

1. Agricultural land management, which consists of improving agricultural technologies in terms of increasing crop resistance to unfavorable natural and climatic conditions and pests (biotechnology), precise application of fertilizers and plant protection products, organizing optimal crop rotations, agro-improvement, and introducing methods of minimum crop cultivation (No-Till, Mini-Till).

2. Livestock management as one of the main sources of methane emissions - improving the feed base for farm animals and improving their well-being (keeping conditions and selection). Here, it is necessary to find a balance between reducing the number of animals and increasing their productivity.

3. Management of organic fertilizers/solid biological waste, which is the basis of closed-loop agricultural production, when livestock waste is used as organic fertilizer in crop production.

4. Bioenergy – production of solid, liquid and gaseous fuels for energy supply of agricultural production from grown biomass. Corn, soybeans, sorghum, crop residues, millet, etc. can be used as raw materials for processing.

5. Organic agriculture is a concept that can make the industry carbon neutral. According to estimates, greenhouse gas emissions from the use of mineral fertilizers annually worldwide amount to about 1000 million tons. With organic farming, their use is completely excluded.

The following can be attributed to the technological areas of adaptation of the rural economy to climate change:

1. Development of new technologies and plant varieties resistant to climate change, adapted to the conditions of areas with a difficult climatic situation.

2. Increasing the efficiency of the irrigation and moistening system of crops, including through the rational use of alternative water sources.

3. Intensification of the use of organic methods of raising livestock and poultry, increasing the importance of practices to ensure the welfare of farm animals (better feeding and housing conditions).

4. Expanding and improving measures for the prudent use of natural resources, including measures to preserve highly fertile soils, reduce the amount of degrading land, and eliminate ineffective forest management practices.

5. Training and supporting the rural population in the field of sustainable agriculture and environmental practices, including consultations, trainings, and public educational events.

At the same time, a mandatory condition for the introduction of adaptation technologies should be taking into account the risks to the country's food security; a balance is needed between economic efficiency and the impact on surrounding ecosystems.

Sustainable development of rural areas in Siberia is possible within the framework of the "Climate Mitigation" scenario, which implies mitigating the risks of global climate change through the development of fallow lands, agroforestry, crop rotation, organic agriculture, etc. [11] The

implementation of this scenario will create the preconditions for the emergence of new organizational forms of rural settlements in Siberia:

1) eco-settlements - rural settlements whose main activity is organic production of agricultural products;

2) tourist settlements - concentration of various types of rural tourism within one rural settlement;

3) rotational settlements, the purpose of which is to manage remote robotic agricultural production in new territories;

4) water and forest protection settlements - specialized rural settlements implementing mitigation measures for agroforestry and hydromelioration;

5) agrotowns - low-rise settlements of landscape-estate type in places of concentration of agricultural production;

6) smart villages - comfortable settlements with highly developed digital infrastructure.

As the conducted studies have shown, the most favorable region for the creation of new rural settlements may be Krasnoyarsk Krai, where the most rapid change in natural zones is predicted towards an increase in the area of more favorable conditions for agriculture and rural population (steppe and forest-steppe landscapes). In addition, increasing the duration of periods with average air temperatures above 0, +5, +10 °C will create comfortable conditions for the development of various types of tourism in the region.

Acknowledgments

The research was supported by the Russian Science Foundation grant No. 23-28-01504.

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